Chapter 5

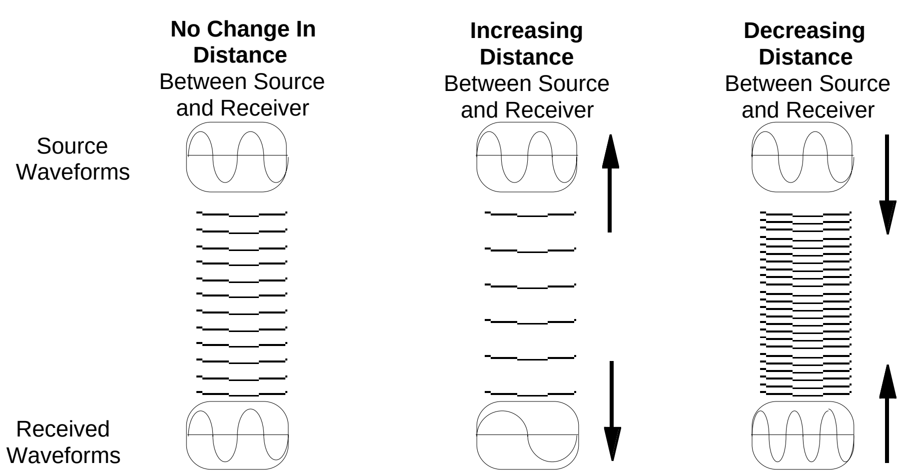
Effects of Motion and Gravity

Objectives: When you have completed this chapter, you will be able to describe the Doppler effect on the frequency of the received particles/waves; describe the significance of spectral red shifting and blue shifting; describe the effects of gravity on electromagnetic radiation; describe superluminal expansion; and define occultation.

Doppler Effect

Regardless of the frequency of electromagnetic waves, they are subject to the Doppler effect. The Doppler effect causes the observed frequency of radiation from a source to differ from the actual radiated frequency if there is motion that is increasing or decreasing the distance between the source and the observer. The same effect is readily observable as variation in the pitch of sound between a moving source and a stationary observer, or vice versa.

Doppler Effects



When the distance between the source and receiver of electromagnetic waves remains constant, the frequency of the source and received wave forms is the same. When the distance between the source and receiver of electromagnetic waves is increasing, the frequency of the received wave forms is lower than the frequency of the source wave form. When the distance is decreasing, the frequency of the received wave form will be higher than the source wave form.

The Doppler effect is very important to both optical and radio astronomy. The observed spectra of objects moving through space toward Earth are shifted toward the blue (shorter wavelengths), while objects moving through space away from Earth are shifted toward the red. The Doppler effect works at all wavelengths of the electromagnetic spectrum. Thus, the phenomenon of apparent shortening of wavelengths in any part of the spectrum from a source that is moving toward the observer is called blue shifting, while the apparent lengthening of wavelengths in any part of the spectrum from a source that is moving away from the observer is called red shifting.

Relatively few extraterrestrial objects have been observed to be blue shifted, and these, it turns out, are very close by, cosmically speaking. Examples are planets in our own solar system with which we are closing ranks due to our relative positions in our orbits about the sun, some other objects in our galaxy, some molecular clouds, as well as some galaxies in what is termed the local group of galaxies.

Almost all other distant objects are red shifted. The red shifting of spectra from very distant objects is due to the simple fact that the universe is expanding. Space itself is expanding between us and distant objects, thus they are moving away from us. This effect is called cosmic red shifting, but it is still due to the Doppler effect.

Distances to extragalactic objects can be estimated based in part on the degree of red shifting of their spectra. As the universe expands, all objects recede from one another at a rate proportional to their distances. The Hubble Constant relates the expansion velocity to the distance and is most important for estimating distances based on the amount of red shifting of radiation from a source. Our current estimate for the Hubble Contant is 60-80 km/s per million parsecs (1 parsec = 3.26 light years).

The spectra from quasars, for example, are quite red-shifted. Along with other characteristics, such as their remarkable energy, this red shifting suggests that quasars are the oldest and most distant objects we have observed. The most distant quasars appear to be receding at over 90% the speed of light!

Gravitational Red Shifting

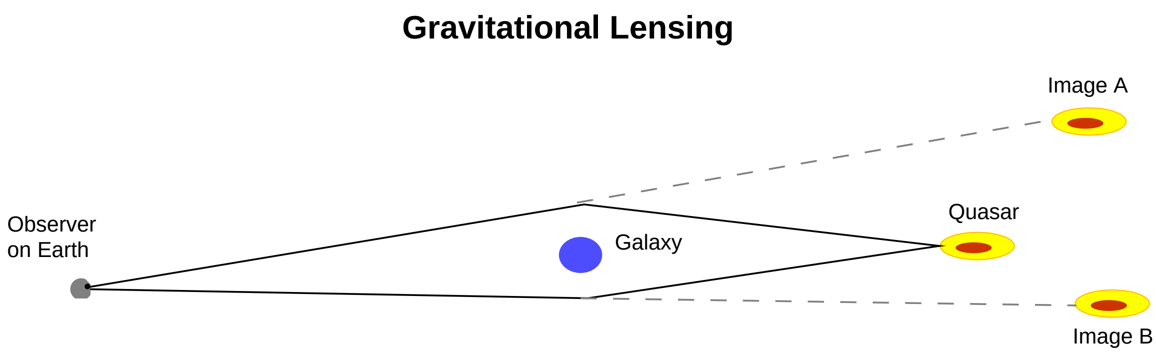
Red shifting, of course, indicates an elongating of the wavelength. An elongated wavelength indicates that the radiation has lost some of its energy from the instant it left its source.

As predicted by Einstein, radiation also experiences a slight amount of red shifting due to gravitational influences. Gravitational red shifting is due to the change in the strength of gravity and occurs mostly near massive bodies. For example, as radiation leaves a star, the gravitational attraction near the star produces a very slight lengthening of the wavelengths, as the radiation loses energy in its effort to escape the pull of gravity from the large mass. This red shifting diminishes in effect as the radiation travels outside the sphere of influence of the source's gravity.

Gravitational Lensing

Einstein's theory of general relativity predicts that space is actually warped around massive objects.

In 1979, astronomers noticed two remarkably similar quasars very close together. They had the same magnitude, spectra, and red shift. They wondered if the two images could actually represent the same object. It turned out that a galaxy lay directly in the path between the two quasars and Earth, much closer to Earth than the quasars. The geometry and estimated mass of the galaxy were such that it produced a gravitational lens effect—that is, a warping of the light as it passes through the space around the galaxy.



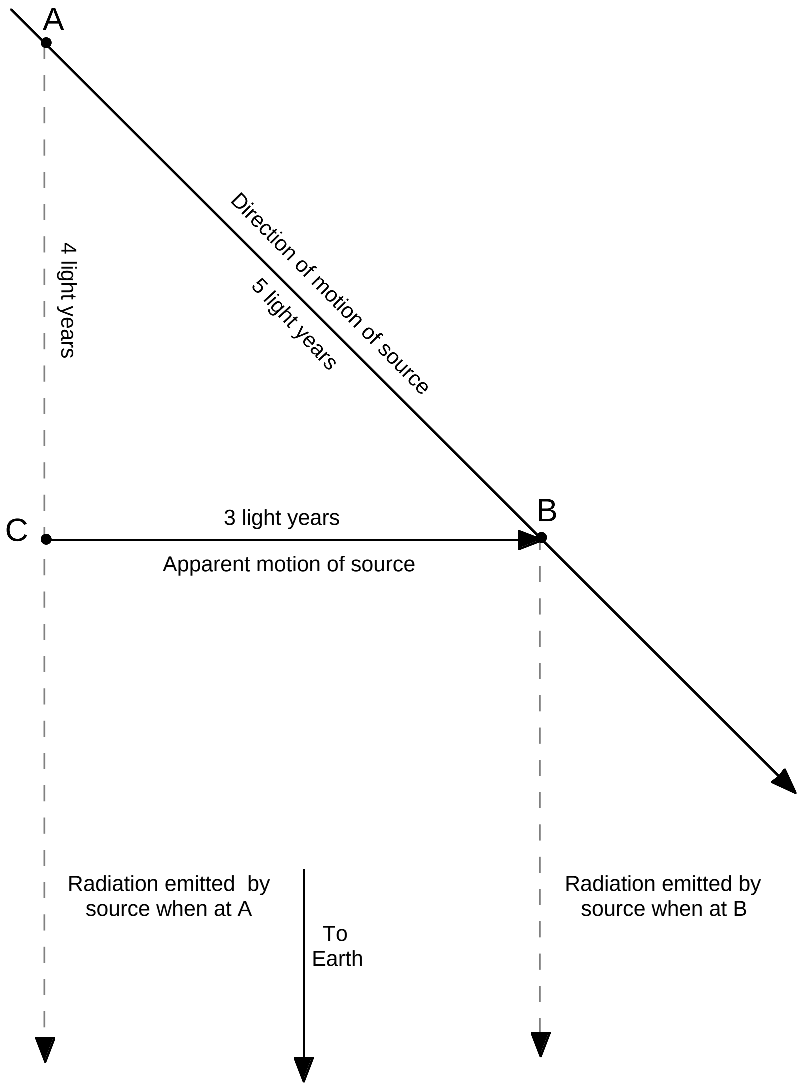
Many other instances of gravitational lensing have now been detected. Gravitational lensing can produce more than two images, or even arcs. Images produced by point-like gravitational lenses can appear much brighter than the original source would appear in the absence of the gravitational lens.

Superluminal Velocities

Some discrete (defined in the next chapter) sources within quasars have been observed to change positions over a brief period. Their motion generally appears to the observer to be radially outward from the center of the quasar image. The apparent velocities of these objects have been measured, and if the red shifts actually do represent the distance and recession velocities of the quasar, then these discrete objects are moving at speeds greater than the speed of light! We call these apparent speeds superluminal velocities or superluminal expansion.

Well, we know this is impossible, right? So astronomers had to come up with a more reasonable explanation. The most widely accepted explanation is that the radiation emitted from the object at the first position (A in the diagram below) has travelled farther and thus taken longer to reach Earth than the radiation emitted from the second position (B), 5 LY from A.

Superluminal Velocity



Suppose A is 4 light years (LY) farther from Earth than B (that is, AC is 4 LY). Moving just a bit under the speed of light, the object takes just over 5 LY to travel from A to B. However, the radiation it emitted at A reaches C in 4 years. As that radiation continues toward Earth, it is one year ahead of the radiation emitted toward us by the object when it arrived at B. When it finally (after several billion years) reaches Earth, the radiation from A is still one year ahead of the radiation from B. It appears to us that the object has moved tangentially out from the center of the quasar, from C to B and (from the Pythagorean theorem) has gone 3 LY in just over one year! That the object appears to travel at nearly three times light speed is only because of the projection effect, with its radiation travelling from A to C in 4 years, while the object itself went from A to B in 5 years.

Occultations

When one celestial body passes between Earth and another celestial body, we say that the object that is wholly or partially hidden from our view is occulted. Examples of occultations are the moon passing in front of a star or a planet, or a planet passing in front of a star, or one planet passing in front of another planet, such as in 1590 when Venus occulted Mars.

An occultation can provide an unparalleled opportunity to study any existing atmosphere on the occulting planet. As the radiation from the farther object passes through the atmosphere at the limb of the nearer object, that radiation will be influenced according to the properties of that atmosphere. The degree of refraction of the radiation gives information about the atmosphere's density and thickness. Spectroscopic studies give information about the atmosphere's composition.

Recap

1. Doppler effect causes the wavelength of energy emitted from an object moving away from the observer to appear _______________ than when it left the source.
2. The spectra of objects moving toward us are __________ shifted.
3. Besides Doppler effect, another cause of spectral red shifting is the pull of ________________ on radiation traveling away from a massive source.
4. The spectra from quasars are quite red shifted, indicating that these objects are moving __________________ from us.
5. The warping of space around massive objects accounts for the effect of _________________ lensing.
6. It is generally accepted that apparently superluminal velocities that have been observed are due to a ____________________ effect.

1. longer 2. blue 3. gravity 4. away 5. gravitational 6. projection

For Further Study

- *Doppler effect:* Kaufmann, 96-97, 460-461; Wynn-Williams, 24-25, 186; Morrison et al., 120-121.
- *Hubble Constant:* Kaufmann, 482-485; Morrison et al., 563, 607-609.
- *Gravitational lensing:* Kaufmann, 445-447; Morrison et al., 581-583.
- *Superluminal motion:* Kaufmann, 515-516.
- *Occultations:* Kaufmann, 243.